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ASSESSING THE UNCERTAINTY OF NUCLEAR DETERRENCE

by

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Biography

Lt Col Robert Steward is a member of the Illinois Air National Guard currently attending Air War College in residence at Maxwell AFB. As a civilian, Robert Steward works in the Earth Science branch at the National Geospatial-Intelligence Agency in St. Louis as a mathematical analysist. As a traditional guardsman, Robert flies with the 126th Air Refuel Wing at Scott AFB. His past leadership positions include Company Commander, Flight Commander, Executive Officer, Operations Officer, and Platoon leader where he has flown the KC-135, UH-60, and AH64. He has held these leadership positions throughout numerous deployments to Iraq, Afghanistan, Kyrgyzstan, Qatar, and several other locations while accumulating nearly 5,000 hours of total flight time to include 1,000 hours of combat flight time. Robert holds a PhD in Mathematics from St. Louis University, an M.A. in mathematics from University of Missouri, and B.S. in Physics from the United States Military Academy at West Point.
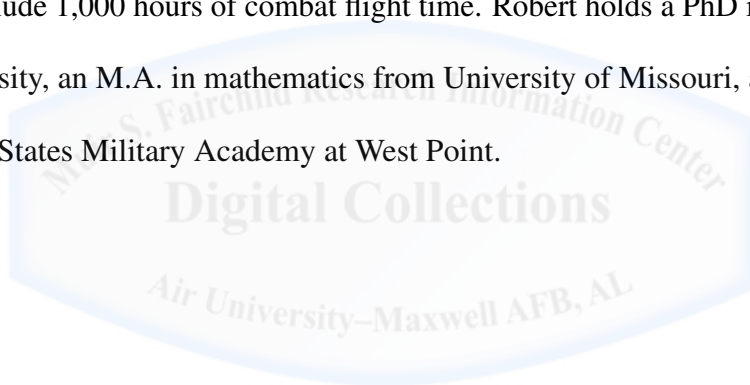
Abstract

Nuclear deterrence theory in its many forms arose as a theoretical architecture with the goal of preventing rather than winning a nuclear war. Although evidence exists that nuclear weapons do deter full out war between nuclear armed rivals, the extent of this deterrent capability is much less clear. This paper analyzes the uncertainty of nuclear deterrence from the standpoint of both classic theoretical arguments and more recent empirical attempts. From both qualitative and quantitative perspectives, this paper finds cause to question the certainty that nuclear deterrence will inevitably hold in the future. Although nuclear war between nuclear rivals has never occurred, this lack of data is largely what makes predicting the continued success of nuclear deterrence in the future so difficult. In fact, from a certain probabilistic point of view, historical empirical evidence is not inconsistent from nuclear war between nuclear rivals being an event that occurs on average once every 100 years. Finally, this paper offers an alternative vantage point to view nuclear deterrence as a risk model rather than strictly as analyzing the probability of a nuclear war event. From this model point of view, risk of nuclear war may be reduced with higher certainty by measures which limit the impact of a nuclear strike rather than relying on inherently uncertain calculations about a rival's intentions.

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"But in all my experience, I have never been in any accident...of any sort worth speaking about. I have seen but one vessel in distress in all my years at sea. I never saw a wreck and never have been wrecked nor was I ever in any predicament that threatened to end in disaster of any sort" E.J. Smith, 1907, Captain, RMS Titanic[1]

1 Introduction

The basic underpinning principle of rational deterrence theory is both longstanding and uncomplicated: A nation does need the full capability to thwart an enemy's attack against its sovereignty or interests, instead, a nation only needs to couple credibility and capacity of exacting unacceptably high levels of retaliatory damage on any such potential attacker. With the advent of nuclear weapons, the question becomes do nuclear weapons change the so-called deterrence equation for nuclear weapons possessing rivals? If so, then to what extent? Despite the apparent simplicity of nuclear deterrence theory, complicated competing interests and nuanced geopolitical forces of symmetric-nuclear-dyads chaotically interact beneath the surface eroding away the certainty of nuclear deterrence. Although theoretical evidence exists that the U.S. nuclear arsenal does indeed serve as a deterrent, the true extent of how its nuclear weapons will deter a future first strike nuclear attack remains much less certain.[2] In particular, U.S. policy makers should not be lulled into a false sense of security that retaining the ability of a massive nuclear retaliation alone will necessarily prevent a nuclear attack on the U.S. homeland because too much uncertainty surrounds estimating the probability of a future first nuclear strike. Furthermore, policy makers should consider nuclear deterrence from a more holistic risk minimizing perspective rather than simply attempting to minimize the probability of a first strike nuclear attack event.

The paper is organized as follows. Section 2 provides basic nuclear deterrence theory

background and offers some statistical evidence that suggests nuclear weapons deter conflict between symmetric-nuclear-dyads. Section 3 examines the uncertainty of nuclear deterrence theory from two competing theoretical arguments regarding how best to minimize the probability of a first strike nuclear attack and illustrates the uncertainty of nuclear deterrence through a historical example. Section 4 highlights past attempts to empirically capture the probability of war between symmetric-nuclear-dyads and finds they fare little better than qualitative measures in accurately assessing the uncertainty associated with nuclear deterrence. Section 5 provides an example illustrating that if a nuclear war event is treated as Bernoulli random variable, then historical observations are still consistent with nuclear war being an event that occurs once every 100 years. Section 6 offers an alternative approach to nuclear deterrence that demonstrates minimizing the risk of nuclear war (as defined by the model) provides advantages over simply minimizing the probability of a first strike nuclear attack. Section 7 highlights the idea that improbable events often are some of the most impactful events and should not be discounted. Finally, four appendices provide supplemental technical material supporting sections throughout this paper.

2   Background: The Nuclear Effect within Deterrence Theory

As Michael Codner explains, the fundamental components of deterrence are "the perception of capability to deliver violence, perception of will, and reputation of the ability to implement intentions effectively" [3] So long as a nation perceives intolerable consequences resulting from a potential conflict, the incentive to initiate any such conflict vanishes. Deterrence theory relies on the assumptions that all interested parties act both rationally and possess all relevant information. All nations must not only play by the rules, they must fully understand the rules in the first place.

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In such cases a weaker nation should not attack a militarily superior enemy, since doing so would almost certainly result in resounding defeat.[4]

Although the logic of deterrence theory is compelling, history nonetheless provides numerous instances of deterrence failing. For example, despite the clear latent power advantage enjoyed by the United States, Japan initiated war with its attack on Pearl Harbor. In the face of world condemnation, Saddam Hussein refused to withdraw from Kuwait despite certain defeat against overwhelming coalition forces certain to attack. More recently, Gazan militants routinely escalated their attack against Israel despite withering retaliation by a far superior Israeli military throughout the 2000's.[5] In fact, a historical lookback reveals weaker countries initiated over 33% of all major conflicts during the 20th century.[6] Whether these attacks occurred because the weaker side perceived a window of opportunity to achieve victory or perhaps miscalculated the capabilities of their opponent altogether, the historical implication remains the same. Militarily superior nations often fail to deter their adversaries from initiating conventional war.

If conventional deterrence often fails, can the same be said about nuclear deterrence? A preliminary review of historical data suggests nuclear weapons do indeed possess a higher deterrence effect than conventional forces alone. Data from the "Correlates of War" data set was used to create Figure 1 by overlaying the percentage of the world's nations possessing nuclear weapons during a given year with the percentage of wars fought during that same year involving nations possessing nuclear weapons. Observing the resulting figure suggests nations with nuclear weapons certainly appear more bellicose. While the number of nations possessing nuclear weapons ranged from as few as 2 to as many as 8 over this sixty-year period, these same nations fought in a disproportionately high percentage of the wars over this same period. On the one hand the analysis of the data reveals nations possessing nuclear weapons have been involved in 19.8%

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Proclivity of War for Nuclear Nations
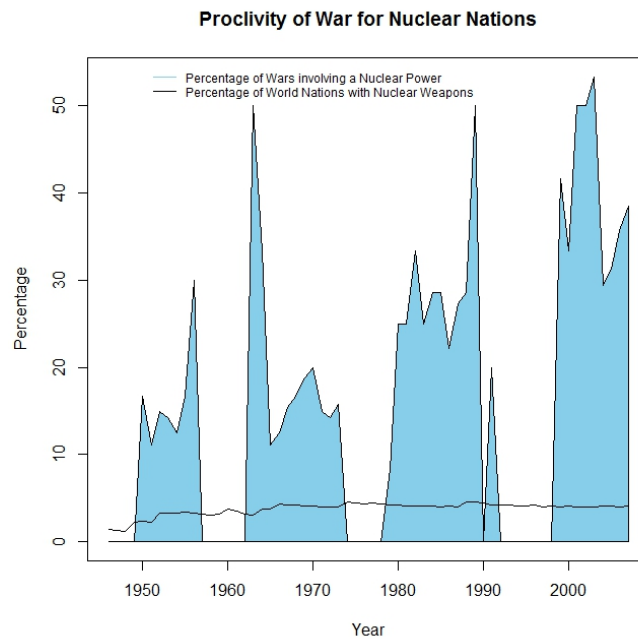
Figure 1: While the fraction of the world's nations with nuclear weapons has remained below 5%, the majority of years these same nuclear powers are engaged in a disproportionately high percentage of the world's wars. [9] [10]

of the world's wars since 1946 (while averaging just 3.75% of the world's nations).[7] On the other hand, (except for the short lived and low intensity Kargil War) none of these conflicts have involved nuclear nations on opposing sides.[8] This basic observation reinforces the validity of nuclear deterrence theory because it seems nations with a penchant for fighting wars simultaneously also have a penchant for not fighting wars against each other.

Perhaps nuclear deterrence works because nuclear weapons fundamentally change conflict escalation. Examining militarized interstate dispute (MID) data from the Cold War suggests nations alter their behavior with regard to initiating conflict escalatory actions after obtaining nuclear weapons.[11] Consider Figure 2 which breaks down hostility levels from MIDs over the Cold War years from 1946 to 1992 along various hostility levels for three categories of nations (1) non-nuclear nations (2) nuclear nations before they obtained nuclear weapons, and (3) nuclear nation after they obtained nuclear weapons. Interestingly, the histograms for the first two

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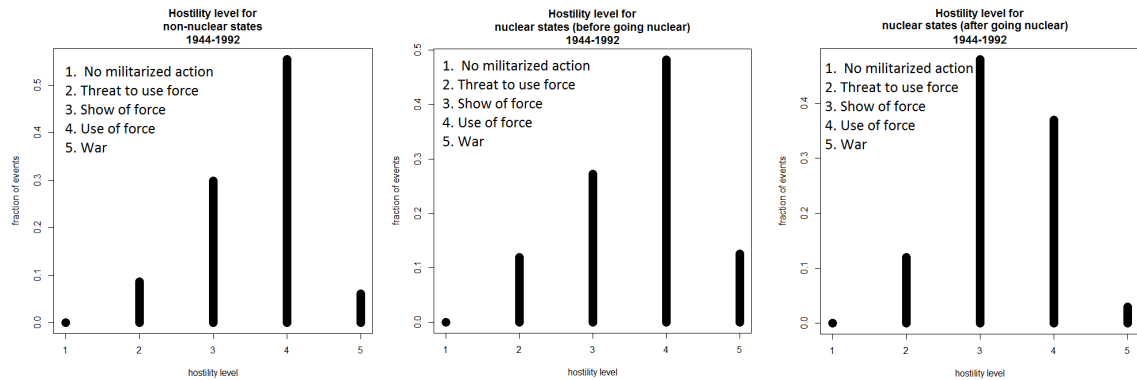
Figure 2: Plots depicting the hostility levels for states without nuclear weapons (left), states without nuclear weapons who would later go nuclear (middle), and nuclear armed states (right). The similarity of the two left histograms juxtaposed to the one on the right indicates nuclear weapons affect how nations handle conflict.
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categories appear highly similar whereas a marked change occurs when nations become equipped

with nuclear weapons. Such an observation indicates that possessing nuclear weapons influences

conflict escalation behavior. In particular, when a nuclear power initiates a MID, the dispute has a

higher propensity to be resolved by a mere show of force. MIDs initiated by non-nuclear states,

however, are more likely to be resolved only after the use of force.[12] Furthermore, once a nation

obtains nuclear weapons, MIDs eventually escalate to war just one-third of the time compared to

when those same nations did not possess nuclear weapons. [13]

Although the descriptive statistics in this section provide evidence that conventional forces

and nuclear forces differ in their capacity to deter, what is less clear is the magnitude of that

extent. Egypt, Syria, Iraq, and Argentina have all attacked countries (or territories of countries)

possessing nuclear weapons, so nuclear weapons certainly do not provide an absolute deterrent

against aggression. [16] While nuclear weapons appear to be correlated with a reduction in the

occurrences of major war between world powers, the uncertainty associated with the probability

of its occurrence creates ambiguity as to whether or not nuclear weapons ultimately save lives

(see Appendix B). Certainly nuclear weapons affect the deterrence equation and seem to lower

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the probability that a nation will incur a sovereignty threatening first strike attack. The apparent historical success of nuclear weapons to deter aggression, however, should not be confused with a certainty that they will continue do so in the future. In an effort to better address this issue of uncertainty surrounding nuclear deterrence theory, both qualitative and quantitative methods may be employed.

3   Qualitative Uncertainty of Nuclear Deterrence Theory

Understanding the true underlying mechanism driving nuclear peace becomes an important question because doing so should help prevent future nuclear wars. Optimists contend that nuclear states exist as rational actors.[17] Nuclear states, therefore, logically perceive the potential aftermath of nuclear weapons employment as so dire that this perception in turn always drives decisions which result in nuclear-exchange risk-minimizing actions. As Thomas Schelling explains, even a small nuclear arsenal coupled with credibility of its use should substantially limit warfare due to "progressive generation of risk".[18] Pessimists, however, argue that nuclear weapons do not make the world a safer place. Although pessimists do not deny the general line of reasoning of nuclear deterrence theory, they nonetheless describe numerous realistic scenarios through accidents, escalation, and miscalculation that would still lead to a future nuclear war.[19]

Herman Kahn argued the United States should pursue a posture of primacy and "win" should nuclear war occur. [20] A reasonable review of Kahn's work suggests that by the United States deliberately choosing not to install damage minimizing measures to actively defeat a nuclear attack, it necessarily leaves more opportunity to be destroyed by nuclear weapons outside of its control. For those factors within a nation's control such as nuclear exercises with the population, building hardened infrastructure, and installing active nuclear missile defense systems,

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a nation potentially dramatically decreases the impact of sustaining a nuclear strike should that event occur. Furthermore, the probability of sustaining a nuclear first strike also becomes smaller because a nuclear armed nation capable of defeating an inbound nuclear attack represents a much less attractive target for an adversary. Although estimating the degree of effectiveness of say a robust modern Ballistic Missile Defense system against a full scale nuclear attack remains within the realm of scientific analysis, determining how such a system affects the probability of that nuclear strike occurring in the first place becomes a far more philosophical argument.

Thomas Schelling led a competing philosophical view on nuclear deterrence theory arguing instead that a "stable" deterrence which intentionally accepts vulnerability actually reduces the chance of nuclear war.[21] Ultimately, Schelling's view on nuclear deterrence of "mutually severe retaliatory threats" dominated U.S. policy throughout the Cold War.[22] With a mutually assured destruction (MAD) scenario in place, Schelling argued that neither side should take steps to establish nuclear defenses because initiating that process would unbalance deterrence perhaps provoking a nuclear attack by the adversary without a nuclear defensive capability. Although Schelling's perspective seems to contradict the logical result of Kahn, the true difference between these lines of thought exists in the window of time from which risk is considered. During the time period from which a nation begins actively installing defense measures to thwart a nuclear attack until measures are in place capable of defeating an inbound nuclear strike, that nation remains vulnerable to sustaining a nuclear strike. A rival nation observing a closing window of opportunity may feel compelled to launch a pre-emptive strike while the balance of power remains intact. As with all philosophical arguments, there is no provable right or wrong conclusion to the Kahn-Schelling debate. Policy makers are then left to make decisions based on qualitative judgements such as which argument seems to better resonate with them.

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As a historical illustration of the uncertainty regarding the probability of a nuclear war event, consider the Cuban Missile Crisis where "rational" actors stumbled precariously close to nuclear war over a comparatively inconsequential matter. Khrushchev's decision to secretly install nuclear weapons in Cuba appears incredibly "reckless" in retrospect given that the Soviets already maintained both a first and second strike capability.[23] For his part, Kennedy's statement that "it shall be the policy of this nation to regard any nuclear missile launched from Cuba against any nation in the Western Hemisphere as an attack by the Soviet Union on the United States, requiring a full retaliatory response upon the Soviet Union" suggests something less than a rational willingness to immediately escalate the crisis to a suicidal nuclear exchange.[24] The Soviets likely already had tactical nukes in place in Cuba positioned to respond against a U.S. attack.[25] Had either the U.S. invaded Cuba as top military advisors urged or Khruschev pressed ahead against the blockade, the Cuban Missile Crisis might very well have mushroomed into World War III. Although the nuclear peace of the 40-year Cold War indicates the probability of nuclear war may be small, the delicate events surrounding the Cuban Missile Crisis suggest the true (but unknown) probability is not small enough.

While some may hail the outcome of the Cuban Missile Crisis as a triumph of nuclear deterrence, such retrospective overconfidence belies the highly unstable circumstances that existed in 1962. Ultimately, the primary mechanism to stave off nuclear attack with Schelling-style nuclear deterrence is psychological in nature and inherently unpredictable. Ensuring the United States does not suffer a first strike nuclear attack by primarily relying on a robust nuclear counterstrike capability requires adversarial leaders of nuclear states to always remain rational, possess the correct information, and avoid catastrophic mistakes. While qualitative methods for describing why nuclear deterrence holds appear convincing, the degree to

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which these arguments can guarantee a future crisis might not develop into nuclear war remains highly subjective. A strategy of nuclear deterrence which solely relies on a massive retaliatory capability works perfectly right up to the moment that it catastrophically fails. Survivors of a future nuclear attack would likely look back in utter bewilderment at how its nation's leaders deliberately chose not to take sensible measures in protecting the homeland from inbound nuclear weapons. Although strategists may successfully argue that nuclear weapons deter to some extent all out war between nuclear armed rivals, they should not convince themselves they are experts in nuclear deterrence theory since they cannot precisely determine the degree of that same deterrence effect. Claiming to know something that is in fact unknowable may be far more dangerous than acknowledging a realistic degree of uncertainty up front.

4   Quantitative Uncertainty of Nuclear Deterrence Theory

Quantitative methods provide an alternative means, in theory, to assess some level of empirical certainty for war between nuclear rivals. Statistical models, in particular, rely on a sufficient quantity of recorded events and a representative sample of data to draw meaningful inference regarding the problem at hand. Two difficulties for developing a credible statistical model describing nuclear deterrence theory are (1) the non-existence of a nuclear war event for a symmetric-nuclear dyad and (2) the small sample size of symmetric-nuclear-dyads composed of rival nations. Problem (1) is a mathematical problem known as data separation which occurs when attempting to calculate the probability of an event that never occurs in the data. Problem (2) causes associated confidence intervals for model results to be so wide that meaningful conclusions cannot be drawn.

In an effort to address the problem of small sample size of symmetric-nuclear-dyads

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composed of rival nations, Rauchhaus created a large data set based on historical data to assess the effectiveness of nuclear deterrence.[26] Each data point in Rachhaus's model involved a dyadic pair of nations for a given year that in principle could have declared war on each other, but in many cases were questionably relevant. Controlling for a number of reasonable independent parameters, appropriately coding war for symmetric-nuclear-dyads as a binary dependent variable, and employing a General Estimating Equation (GEE), Rauchhaus purports to calculate an odds ratio comparing the likelihood of war for a symmetric-nuclear-dyad versus a non-nuclear dyad. Although Rauchaus's work does represent a sophisticated attempt at modeling the nuclear deterrence question, Rauchhaus ultimately attempts to hypothesize about the future based on evidence from the past that simply does not exist. By including a large quantity of seemingly irrelevant dyad pairs in the data set, he introduces significant bias into his results. Furthermore, by ignoring the problem of separation in his data set, Rauchhaus's results become altogether mathematically dubious. Rauchhaus's final conclusion, that with 95% confidence, non-nuclear dyads range from 893,000 to 8,531,000 times more likely to go to war [27] than symmetric-nuclear dyads appears unconvincing.

Recognizing the shortcomings of Rauchhaus's work, Bell and Miller[28] have gained recent attention by improving upon previous methodologies and more rigorously handling technical problems such as the issue with separation in data. Unfortunately, if Bell and Miller's methods are quantitatively more sound than previous works, their conclusion remains nonetheless underwhelming. Bell and Miller's primary result of interest for the purposes of this paper is a calculation employing a Firth Logit regression technique that describes an odds ratio for a non-nuclear dyad going to war versus a symmetric-nuclear dyad going to war. For example, a calculated ratio value of .5, 2, and 1 should be interpreted as a non-nuclear dyad being half, twice,

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or equally as likely to go to war than a symmetric-nuclear dyad, respectively. Observing Bell and Miller's results as given in Table (1) reveals their empirical work possesses substantial uncertainty relating to the effect of nuclear weapons on deterring war between symmetric-nuclear-dyads. More specifically, whether or not the Kargil War should be classified as a war or a MID (a difference of only about 100 battle field deaths) translates into a 95% confidence interval that non-nuclear dyads are anywhere from .077 times to over 30 times as likely to go to war as nuclear dyads. While Bell and Miller's results certainly seem more reasonable than Rauchhaus's conclusion, they also fail to provide any type of sharp conclusion as to the certainty of how well nuclear weapons deter conflict for symmetric-nuclear dyads.

	Ratio Estimate	95 percent confidence interval
Kargil excluded	1.606	[.088, 30.079]
Kargil included	.471	[.077, 2.985]

Table 1: Whether or not the Kargil War is actually included in the data set or not means Bell and Miller results can only provide a 95% confidence interval value that symmetric-nuclear-dyads are somewhere between .077 and 30 times as likely to engage in war with each other.

Yet another quantitative attempt to empirically assess the nuclear weapons effect on deterrence was conducted by Vipin Narang. Narang recognizes that fundamentally states pursue nuclear weapons as a hedge against some baseline security threat. Yet how states choose to posture their nuclear arsenal substantially affects their deterrence effect.[29] Narang presents a convincing argument that in fact how a nation postures its nuclear weapons should influence its ability to deter against aggression. His empirical evidence which attempts to tease out the quantifiable differences in deterrence as a function of nuclear posture, however, does not quantify the probability of future nuclear war for a symmetric-nuclear-dyad. Although Narang provides a detailed empirical model that goes further than previous work by establishing that how nations posture nuclear weapons also affects the capability to deter, the basic question of to what extent

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remains unanswered.

Aside from the technical issues discussed above involved in quantifying the probability of war between symmetric-nuclear-dyads, there is a more fundamental question related to cause and effect. While all the models discussed above attempted to establish a correlation between the possession of nuclear weapons and deterrence, none even approached the topic of causation. Besides the fear of nuclear war, many other possible reasons exist as to why major powers have not engaged in full out war since the end of World War II. In particular, with the exception of North Korea, nuclear powers possess a tremendous amount national wealth that would be subject to destruction in any type of war against a powerful adversary. Furthermore, the interdependence of national economies, reliance on global commons, and interconnectedness of culture made possible with new technology all represent powerful forces that strongly encourage rival powerful nations to resolve disputes peacefully. Ultimately, the proposed quantitative methods for assessing the nuclear peace theory up to this point offer the same conclusion as do qualitative methods. Nuclear weapons probably deter symmetric-nuclear-dyads from engaging in full out war, but to what extent remains uncertain.

5 An Illustrative Example

When general deterrence breaks down, how do nuclear weapons affect crises between nuclear rivals? Although numerous minor conflicts resulted in increased tensions between nuclear powers at various times in the past 60 years, only three cases standout as times where nuclear war credibly loomed. The Cuban missile crisis, the Yom Kipper War, and the Kargil War all represent clear cases where nuclear powers faced clear existential threats to their sovereignty. In each case the nuclear powers involved took the extraordinary measure of preparing forces for a possible

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nuclear strike. During the Cuban missile crisis, the United States increased its nuclear readiness level to DEFCON 2 just one level below "imminent nuclear war".[30] During the Yom Kipper War Israel reportedly had armed eight F-4 with nuclear weapons when their sovereignty remained in question as the Egyptians and Syrians advanced toward Israel.[31] Finally, the Kargil war represents a particularly volatile situation where the world looked on in fear as two historical adversarial nuclear neighbors teetered on the verge of all-out war for a few precarious weeks in the summer of 1999.

Unfortunately for the modeler attempting to quantitatively assess the probability of nuclear war, a sample size of 3 does not provide a statistically relevant means of drawing inference. As a result, researchers have typically handled these crises as individual case studies. Although a robust statistical model is not possible with a sample size of 3, some insight into the probability of nuclear war can nonetheless still be drawn. Given a nuclear crisis exists, suppose the event of the crisis becoming a full blown nuclear war may be modeled as a Bernoulli random variable. With these assumptions in hand along with the historical knowledge that nuclear war did not occur in these three instances, Figure (3) plots the *probability of nuclear war not occurring in three distinct trials* against the *true probability of nuclear war given a nuclear crisis*. What the plot reveals is that if the probability of nuclear war occurring given a nuclear war is zero, then naturally a 100% chance exists to observe the outcome of the historical events, namely nuclear war did not occur. More revealing, however, is that if the chance of nuclear war occurring given a nuclear crisis was in reality 10% probable, then still about a 70% probability exists to have observed a de-escalation of these three crises as well.

The results of this simple Bernoulli experiment suggest that while nuclear war is not a common event, the probability of its occurrence may possibly be much further from zero than

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Probability Nuclear War Does not Occur After Three Crises versus the probability of Crisis becoming a Nuclear War
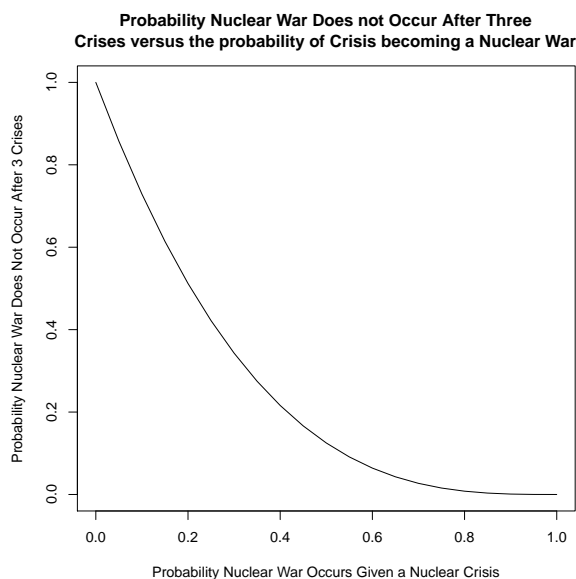
Figure 3: Given that the past three historical nuclear crises did not escalate into nuclear war, what are the chances the next nuclear crisis will escalate to nuclear war? The plot suggests if nuclear war can be considered a Bernoulli random variable, then the chances for nuclear war even after a nuclear crisis occurs is likely low, but not necessarily comfortably low enough.

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researchers realize. With only three recorded true nuclear crises in the past 60 years, events escalating to the credible possibility of a nuclear exchange are relatively rare. Given that each nuclear crisis has failed to escalate to nuclear war indicates the probability of actual nuclear war is likely rarer still. The lack of empirical evidence allows for enough uncertainty relating to the probability of nuclear war, however, that the true probability of nuclear war may nonetheless be far above zero. Appendix D illustrates a numerical example which shows that historical events are entirely consistent with nuclear war (treated as a Bernoulli random variable) that statistically occurs on average once every 100 years.

6 A Nuclear Deterrence Risk Model

The general uncertainty regarding the effectiveness of the United States' nuclear posture to deter a future nuclear first strike attack becomes especially complex due to the stakes at play. The

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principles of nuclear deterrence theory as applied by the United States cannot just hold true most of the time. Instead, these principles must hold true all of the time or fundamentally risk the order of the free world. Rather than considering deterrence strictly from a perspective of lowering the probability of nuclear war, a more holistic approach would be to instead attempt to minimize the risk of nuclear war altogether. Consider equation (1) which represents the risk, R, to the United States of receiving a first strike nuclear attack:

$$R = I(s,d) \times P(t) \tag{1}$$

where $I(s,d)$ represents the impact of a first strike nuclear attack on the U.S. homeland as a function of both the scope of the attack, s, and the national defenses in place, d, while $P(t)$ represents the probability of the U.S. incurring a first strike nuclear attack over some time period, t, starting at the present.[33]

While Appendix A provides a formal description of equation (1), intuition for its meaning can be gained by examining the cases of when either I or P could be made identically equal to 0. If $I = 0$, such as in the hypothetical case of a perfect nuclear defense system, then naturally $R = 0$ regardless of how high the probability, P, of receiving a first strike nuclear attack. Similarly so with the $P = 0$ case. In reality, the unknown value of P is nonzero but probably small as Section 5 shows. The maximum value of I, however, is probably quite large because of the known destructive power of nuclear weapons, the size of rival nuclear arsenals (i.e. Russia), and the very limited capacity of the U.S. to defeat inbound nuclear weapons. The question then becomes how best to minimize the risk, R, given the constraints of the international system?

Let $R_{max,t}$ represent the maximum risk U.S. policy makers would be willing to accept for a given time period, t, and let I_{max} represent the minimal upper bound for the function I. Because

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A plot of the Risk (R) of sustaining a first strike nuclear attack against the product of Impact (I) of such an event and the probability (P) of that event occurring.
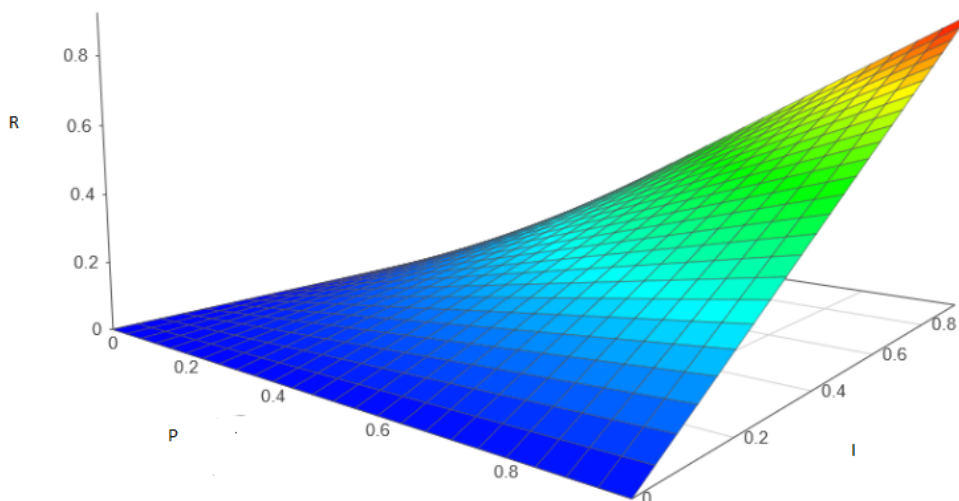
Figure 4: Equation (1) visualized.
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I_{max} would be so intolerably high without any current means of minimizing the effect of a nuclear strike, the probability of nuclear war should be reduced so low that the risk of sustaining a nuclear strike always remains below $R_{max,t}$. The problem, however, becomes determining the probability that the United States will sustain a first strike nuclear attack because of the uncertainty associated with P. Is R currently actually greater than $R_{max,t}$ and we just do not realize it? Equation (1) provides an alternate vantage point to more precisely answer this question.

Approaching nuclear deterrence from the context of equation (1) allows a nation to pursue risk minimizing measures in more broad terms and rely less on unpredictiable advesary intentions. In other words, approaching nuclear deterrence from a risk minimizing perspective potentially reduces overall risk of nuclear war compared to the traditional approach of focusing only on the probability of a nuclear strike event. Additionally, there are at least three other potential advantages in pursuing nuclear deterrence from the context of equation (1) that are candidates for

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further research.

1. Calculating a return on investment for lowering R becomes clearer than for a similar calculation on P alone. The reason for this increased clarity is due to the quantifiable nature of measuring I_{max}. For example, proving the extent of how a \$1 trillion-dollar investment into modernizing the nuclear triad actually translates into lowering the probability of a first strike nuclear attack is nearly impossible because of the uncertainty associated with the psychology of an adversary. Estimating the number of lives saved by an advanced ballistic missile defense technology investments, however, should in theory be a far more straight forward task.

2. Improving nuclear deterrence becomes potentially more efficient. Because the value of P is low and the value of I_{max} is high there is almost certainly an element of diminishing returns at play in pursuing a P minimizing approach alone. For example, if $P = .01$ and $I_{max} = .75$, then the marginal cost of lowering R by 10% is likely much less by focussing on I_{max} alone versus focussing on lowering P alone because P is already close to zero.

3. Comparing deterrence strategies become more simplified. Equation (1) provides a more holistic framework from which nuclear deterrence decisions and arguments may be measured and compared. Appendix C provides an example of how this might be done.

7 Appreciating the Possible

Nassim Taleb describes "black swans" as improbable events that have highly impactful long lasting consequences.[35] For example, the U.S. housing crash of 2008 along with its world wide ripple effect or the sudden transformative development of the internet are both typical examples

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of black swans. What makes black swans particularly destabilizing to the status quo is the human tendency to fail to acknowledge and prepare for their possibility in the first place. More specifically, Taleb argues that governments, businesses, and academic institutions tend to focus primarily on the known rather than fully consider current circumstances in a general context. [36] The practical consequence of this miscalculation often leads to an oversimplification of models and an over confidence in future events. A person or organization that believes it knows more than it actually does tends to disproportionately focus on irrelevant circumstances at the expense of adequately preparing for highly impactful events.

A historical review of major world conflicts in the 20th century reveals many of these conflicts were precipitated by a chain reaction of unpredictable highly irregular events cascading into an exploding crisis. While the improbable assassination of Arch Duke Ferdinand sparked a four-year long war resulting in 40 million dead, the fortuitous discovery of missile base construction in Cuba led only to a collective sigh of relief for hundreds of millions as nuclear war was narrowly averted. Small tweaks in circumstance in either of these examples could have easily resulted in entirely different results in both cases. Although governments tend to project a sense of total control over their surrounding environments, randomness nonetheless exists inextricably intertwined with the course of world events. If history is a reliable indicator, however, one thing can be said with relative certainty. Should nuclear war ever occur, we will not see it coming.

With much of the nuclear triad apparatus approximately 60 years old, many argue that the time to modernize the triad is now. Since nuclear war between the United States and Soviet Union did not occur with reliance primarily on a MAD framework in place, perhaps similarly only maintaining a massive nuclear retaliatory capability will be the best course for preserving the future peace as well. The unknowable counterfactual is whether or not the cold war would

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have remained cold had the U.S. chose to invest in active defenses rather than massive offensive capabilities instead. According to the White House, the proposed full modernization plan of the nuclear triad will cost close to $1 trillion over the next 30 years.[37] Upgrading a massive nuclear force guarantees U.S. capability to annihilate any nation on earth in the foreseeable future. If such a strategy comes at the expense of investing in a robust national defense against a nuclear attack, then the U.S. intentionally chooses to avoid steps that would perhaps substantially lower the value of I (and hence more importantly R) from equation (1) given above. Without anyway to reliably determine the value of P, the U.S. fails to minimize its risk to nuclear war in the long run.

8   Conclusion

Both the dialectical and empirical evidence discussed above indicate that the probability of the United States sustaining a nuclear first strike attack is both positive (i.e. non zero) and small. What is not fully clear, however, is the precise extent to which that probability is small. Nothing about the current collection of data or arguments can distinguish between nuclear war being an event that should occur once every 10,000 years or once every 100 years. Following the line of reasoning provided by Schelling, the U.S. has largely chosen not to invest in a defense against a nuclear strike despite a range of measures that are both technologically and economically feasible. Such an approach, however, presumes to understand the probability of a nuclear war event more than is reasonably possible. Ultimately, the goal of nuclear deterrence should be to reduce the risk, R, of nuclear war as low as possible rather than its probability, P, alone.

   If nuclear weapons have diminished the chances of a World War III scenario, then they have dramatically increased the stakes of such a calamity as well. While there is reason to believe that a link exists between nuclear weapons and fewer wars between major power, as Keith Payne

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notes, "it is [also] impossible to predict the next failure in deterrence." [38] So long as rational actors remain in control of nuclear weapons (and do not make mistakes), it seems the current status-quo can persist indefinitely. Unfortunately, there exist no guarantee that mature nuclear powers will always act rationally or not make mistakes. Furthermore, emerging nuclear powers such as North Korea, Iran, and possibly others could significantly impart further uncertainty with P's true value. Precisely because of these unknown unknowns, nuclear deterrence cannot guarantee a future nuclear attack will not occur. By solely relying on a massive retaliation deterrence strategy, the United States accepts a simplified world model and intentionally avoids fully preparing for the ultimate black swan event.

Appendix A

Let $I(s, d)$ represent the impact of a first strike nuclear attack on the U.S. homeland as a function of the scope of the attack, s, and the level of nuclear defenses in place, d. Let $\mathcal{S}$ represent the set of all possible first strike scenarios that might occur against the U.S. homeland and let $\mathcal{D}$ represent the set of all possible nuclear defense systems that could theoretically be put into place. Clearly, $I(s, d)$ is a bounded non-negative function. Since any non-negative bounded function may be mapped to the unit ball by dividing by its $limsup$, without loss of generality $I(s, d)$ may already be assumed to normalized such that

$$I : \mathcal{S} \times \mathcal{D} \to [0, 1]$$

$$s \times d \mapsto I(s, d).$$

In particular, the value 0 identifies the situation where no impact occurs to the United States after sustaining a first strike nuclear attack. For example, in the idealized scenario of the U.S. owning a perfect missile defense system, d_{ideal}, $I(s, d_{ideal}) = 0 \; \forall \; s \in \mathcal{S}$. The value 1 identifies the other extreme where the United States is completely annihilated after a nuclear strike.

If $P(t)$ represents the probability of the U.S. incurring a first strike nuclear attack over some time period, t, starting at the present, $t_{present}$, then

$$P : [t_{present}, \infty] \to [0, 1]$$

$$t \mapsto P(s).$$

Explicitly, 0 and 1 correspond to a 0% and 100% probability of the United States sustaining a first strike nuclear attack over some time period, respectively. Notice that for $t_2 > t_1$ it necessarily

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follows that $P(t_2) \geq P(t_1)$. While in reality P may also vary to some extent with s as well, this subtlety is not considered in this paper. Hence, the functions I and P may be considered independent from each other.

With the above notation and definition in hand, the nuclear risk equation may be expressed as

$$R : (\mathcal{S} \times \mathcal{D}) \times [t_{present}, \infty] \rightarrow [0, 1]$$

$$(s \times d) \times \ t \mapsto I(s, d) \cdot P(t).$$

that is,

$$R = I(s, d) \times P(t).$$

Appendix B

The descriptive statistics in Section 2 indicate that empirical evidence exists for the efficacy of nuclear weapons to deter large scale war between nuclear rivals, but do they actually save lives? A limitation of the descriptive statistics in Section 2, along with intuition, involves understanding the uncertainty associated with that same lowered probability. Using the same formulism provided in Appendix A, let $P_{conventional}$ and $P_{nuclear}$ represent the probability of full scale war occurring between a non-nuclear dyad and nuclear dyad, respectively. The statistical evidence in Section 2 then implies that for any t,

$$1 > (\Delta P = P(t)_{conventional} - P(t)_{nuclear}) > 0, \tag{2}$$

but no other precise conclusion can be drawn. Furthermore, since presumably

$$1 > (\Delta I = I_{nuclear} - I_{conventional}) > 0, \tag{3}$$

nations may in fact assume higher risk by posturing a nuclear weapons defense rather than a conventional defense alone. Explicitly, if $\Delta I > \Delta P$ holds, then even if full scale war occurs more frequently between non-nuclear dyads, the overall risk of war between nuclear dyads may nonetheless be higher. The uncertainty associated with the occurrence of a nuclear event between nuclear dyads means an equal level of uncertainty exists as to the risk that nuclear nations accept as well.

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Appendix C

While the arguments presented by Schelling and Kahn appear to contradict each other, in the context of equation (1) they are actually arguments simply focused on different values of t. Let I_{nd} represent the impact of a nuclear strike with no defenses and let I_{def} represent the impact of a nuclear strike with a fully installed robust nuclear defense system. Clearly, $I_{nd} > I_{def}$. Furthermore, Kahn argues $P_{nd} > P_{def}$ since a nation would be foolhardy to lauch a first strike nuclear attack against a nuclear nation that could defeat that strike. It therefore follows that $R_{nd} > R_{def}$.

For the Schelling case, first let T represent the time required for a nation to both develop and install a robust nuclear strike defense. Recall from Section 6, that $R_{max,t}$ is the maximum amount of risk that policy makers can accept for sustaining a nuclear first strike over some time period, t. Schelling's arguments may then be summarized for $t < T$ that actively building nuclear defense causes $R_t > R_{max,t}$ due to an increase in $P(t)$ and no change in I.

A certain illogic of Schelling's argument may be found, however, by considering equation (1) from the rival nation's perspective. In a mutually assured destruction scenario, if a nation launches a nuclear first strike, then its risk, R, becomes maximized. So regardless of how proactive installing an active nuclear defense might be, such an action from a rival is still far more desired than an inbound nuclear missile strike event. Nonetheless, because of the uncertainty associated with any estimate value of $P(t)$, Schelling's argument can neither be proven nor disproven.

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Appendix D

Recall, the probability mass function for the Binomial distribution may be expressed as

$$f(k; n, p) = \binom{n}{k} p^k (1-p)^{(n-k)} \tag{4}$$

where n represents the total observations, k represents the number of occurrences of a distinct Bernoulli event, and p represents the probability of that district Bernoulli event occurring on a single trial. If the probability of some event, A, occurring is 20%, then after three total observations equation (4) gives a 51% probability that the event will not have occurred. In the approximate 60 year history of rivalries between symmetric-nuclear dyads, three true nuclear crises have occurred. The best empirical conclusion that can be drawn from a frequentist perspective is that in a given year there is a $1/20$ probability of a nuclear crisis occurring. If $p_N(y)$ represents the probability of nuclear war occurring in a given year, y, and a nuclear war is always precipitated by a nuclear crisis, then p_N may be conditionally expressed as

$$p_N(y) = p_N(y|C)p(C)$$

where $p_N(y|C)$ equals the probability of a nuclear war occurring given a nuclear crisis has occurred and $p(C)$ equals the probability of a nuclear crisis occurring. Assume there is a 20% probability of that crisis becoming a full blown nuclear war. If $p_N(y)$ is a Bernoulli r.v., the expected time, t, in years from the beginning of nuclear rivalries until the first nuclear war would be $E[t] = 1/p_N(y) = 1/(.05 \cdot .2) = 100$ years. Whether a nuclear war event should occur on average once every 100 years or once every 10,000 years cannot be meaningfully distinguished

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from the empirical historical data.

Notes

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[9] Plot and calculations done with the R statistical software

[10] Data from the Correlates of War data set was used to construct this figure. Sarkees, Meredith Reid and Frank Wayman (2010). Resort to War: 1816 - 2007. Washington DC: CQ Press.

[11] Sarkees, Meredith Reid and Frank Wayman (2010). Resort to War: 1816 - 2007. Washington DC: CQ Press.

[12] Calculation based on data analysis from the Correlates of War Data Set as illustrated in Figure 2. Sarkees, Meredith Reid and Frank Wayman (2010). Resort to War: 1816 - 2007. Washington DC: CQ Press.

[13] Calculation based on data analysis fromt he Correlates of War Data Set. Sarkees, Meredith Reid and Frank Wayman (2010). Resort to War: 1816 - 2007. Washington DC: CQ Press.

[14] Plot and calculations done with the R statistical software

[15] Data from the Correlates of War data set was used to construct this figure. Sarkees, Meredith Reid and Frank Wayman (2010). Resort to War: 1816 - 2007. Washington DC: CQ Press.

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[32] Plot and calculations done with the R statistical software

[33] For ease of notation, s, d, and t will be suppressed throughout the remainder of the paper and explicitly annotated only as required by context.

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[34]Plot and calculations done with the R statistical software

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